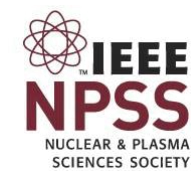




**COMSOL
CONFERENCE**
2016 MUNICH

Munich, 2016



Credits

Project RFMEFI60714X0008 “**Development of methods for complex diagnostics of onboard equipment of spacecraft on resistance to arcing**” of the Ministry of Education and Science of Russian Federation

Participants:

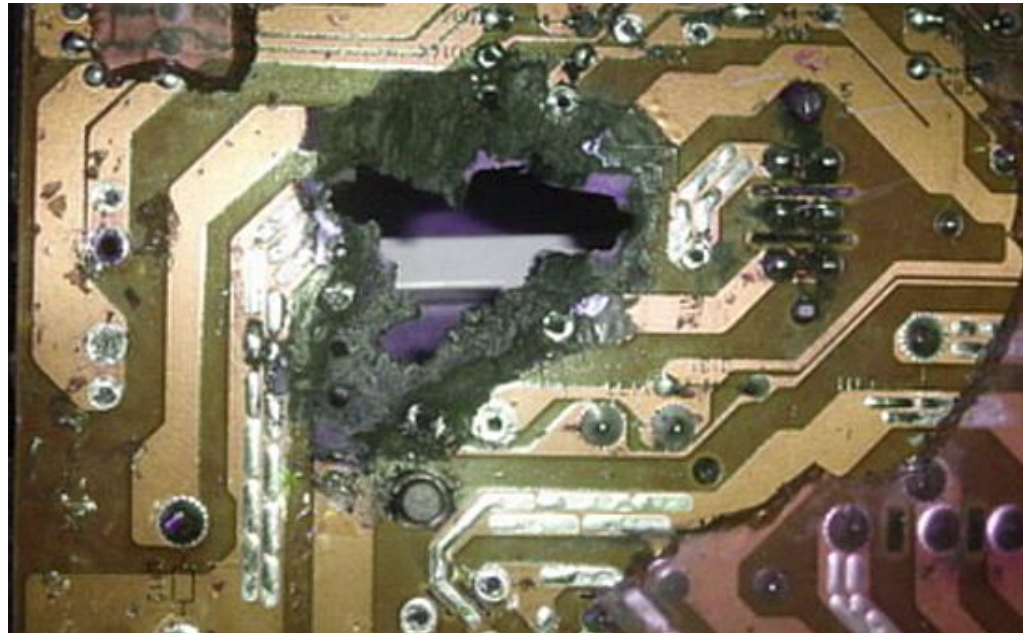
- **Institute of High Current Electronics, Tomsk, Russia**
- **Tomsk State University, Tomsk, Russia**
- **Tomsk State University of Control Systems and Radioelectronics, Tomsk, Russia**



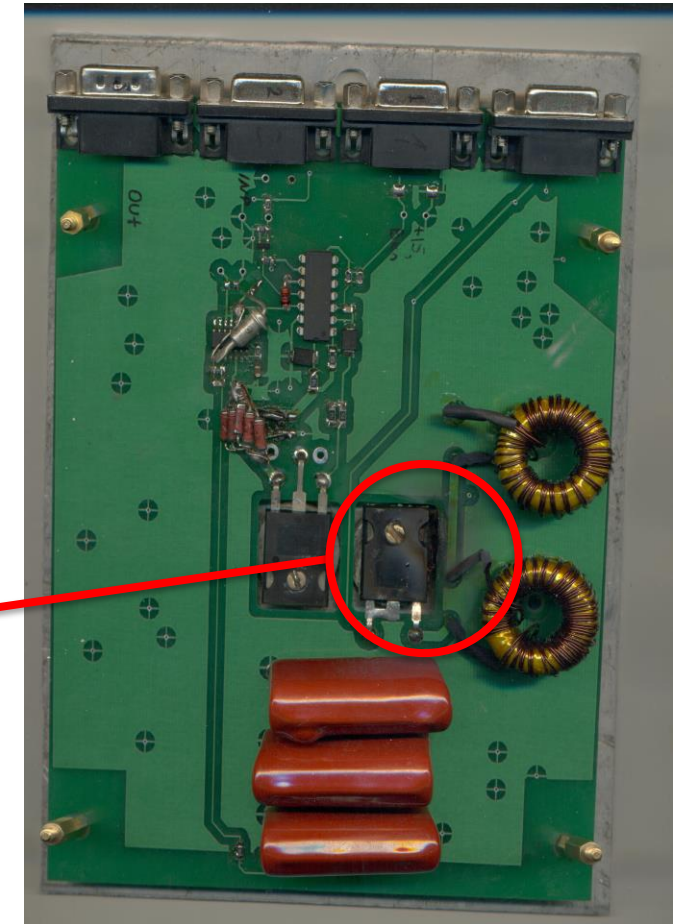
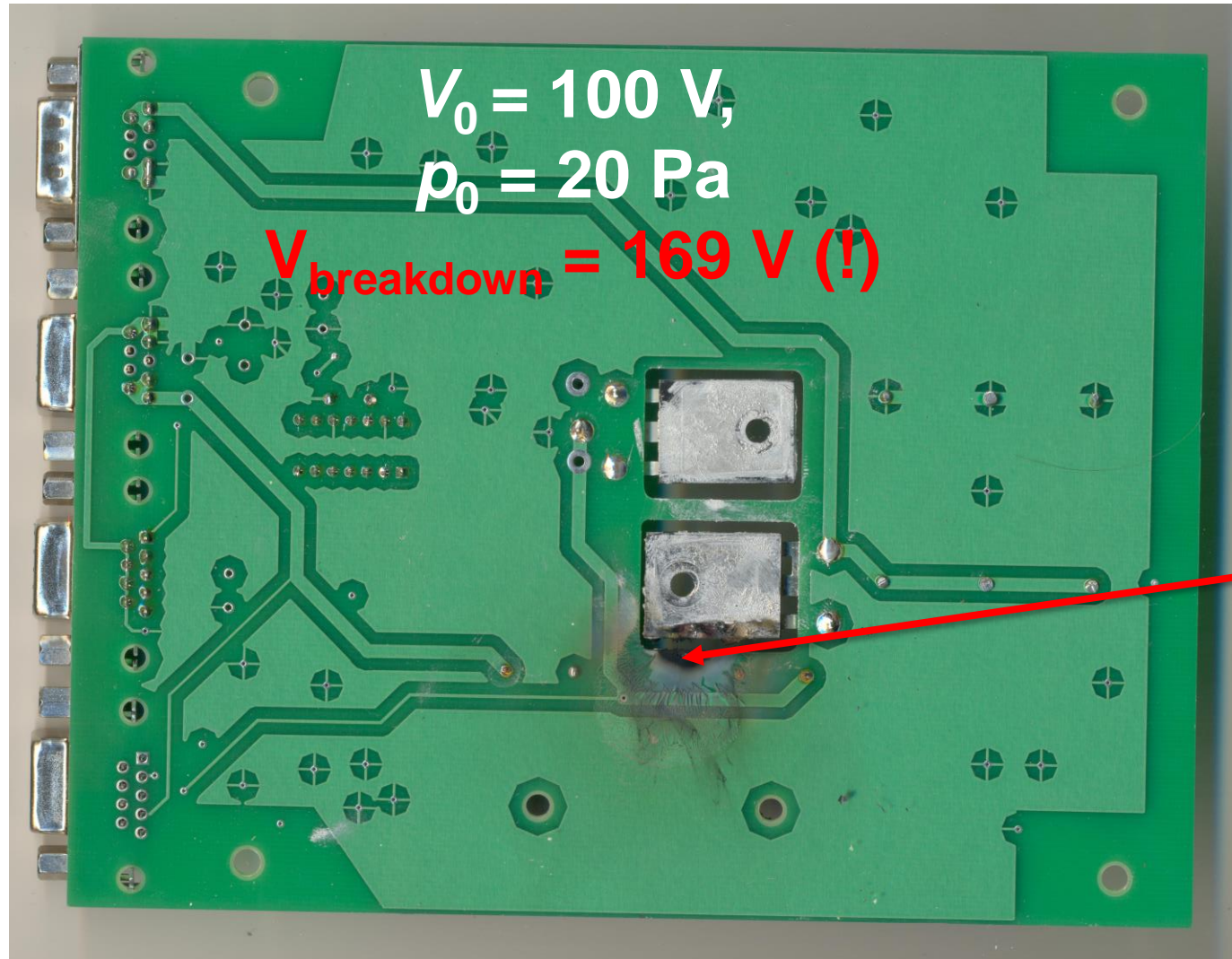
Root problem

Today, in civil spacecraft the electric arcing is one the main factors leading to partial or complete failure of electronic equipment.

This problem escalates with the increase of operating voltages from 27 Volts up to 100 Volts since 2000.

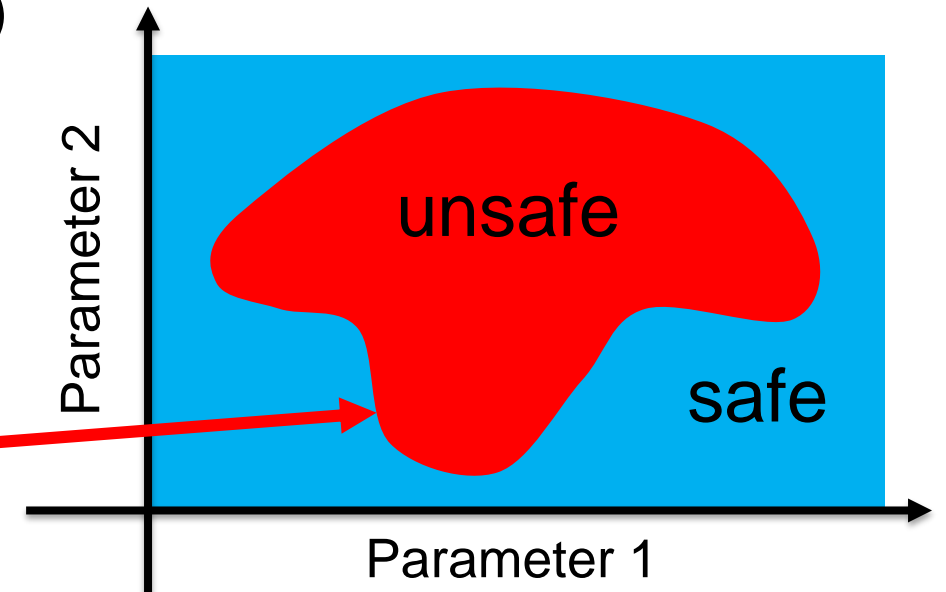
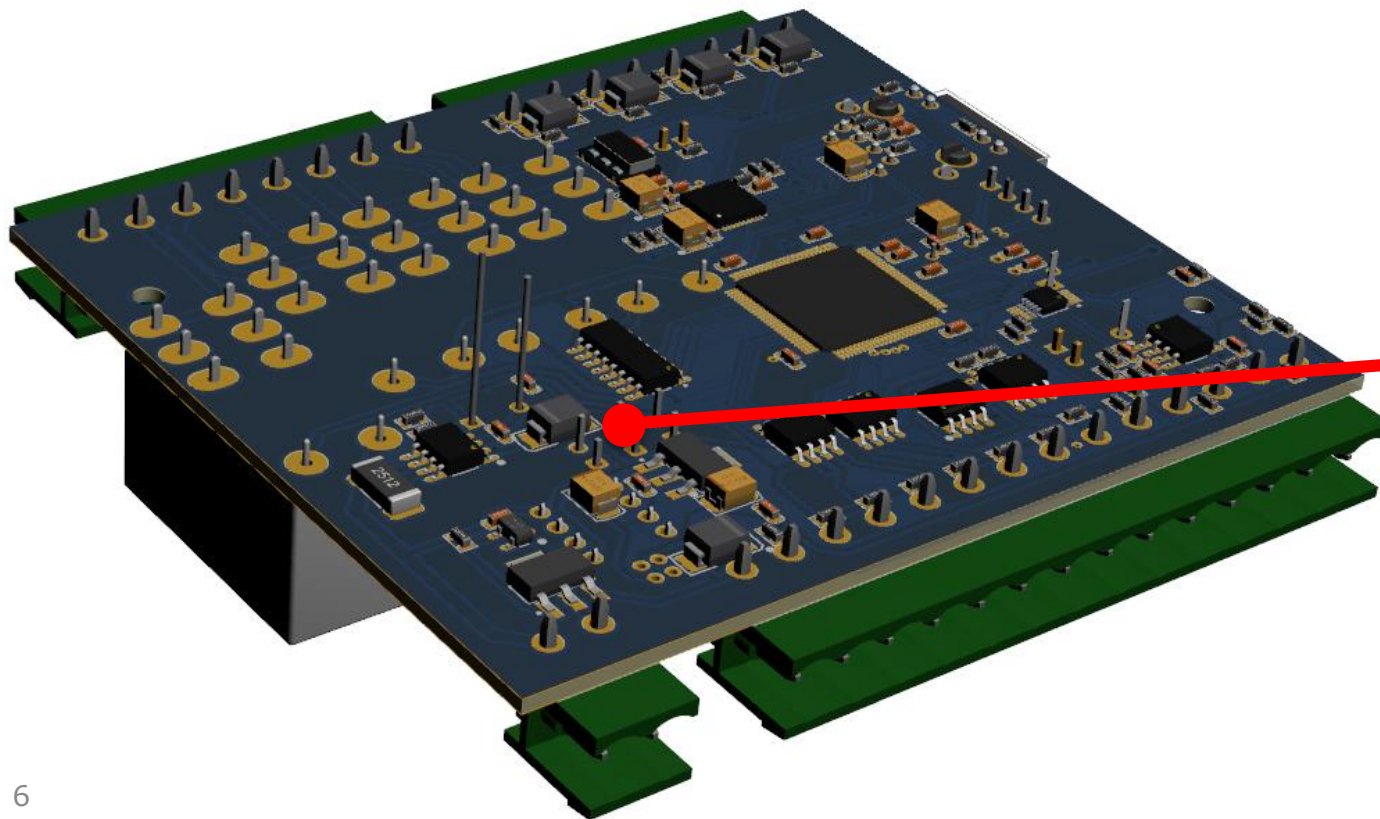


Experimental example of primary arc below Paschen's minimum (in Ar)



What is diagnostics ?

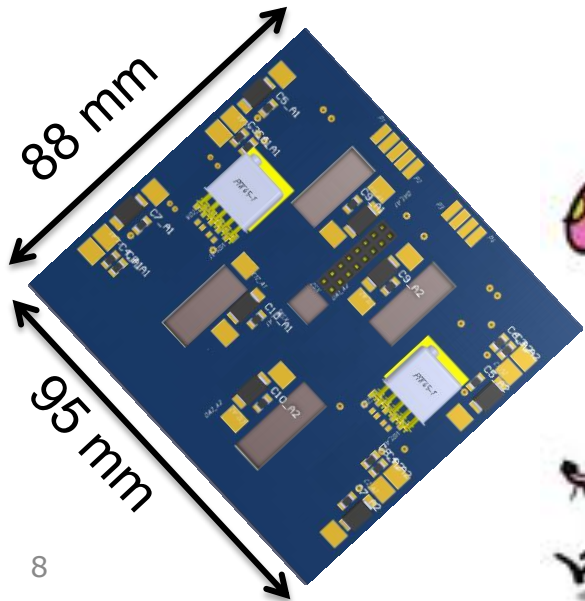
- Search for the region where the self-sustained discharge is most probable;
- Investigate multiple conditions of arcing with respect to variation of main parameters (pressure, electrons emission, etc.)



Multiscale problem (Full-scale DC-discharge simulation)

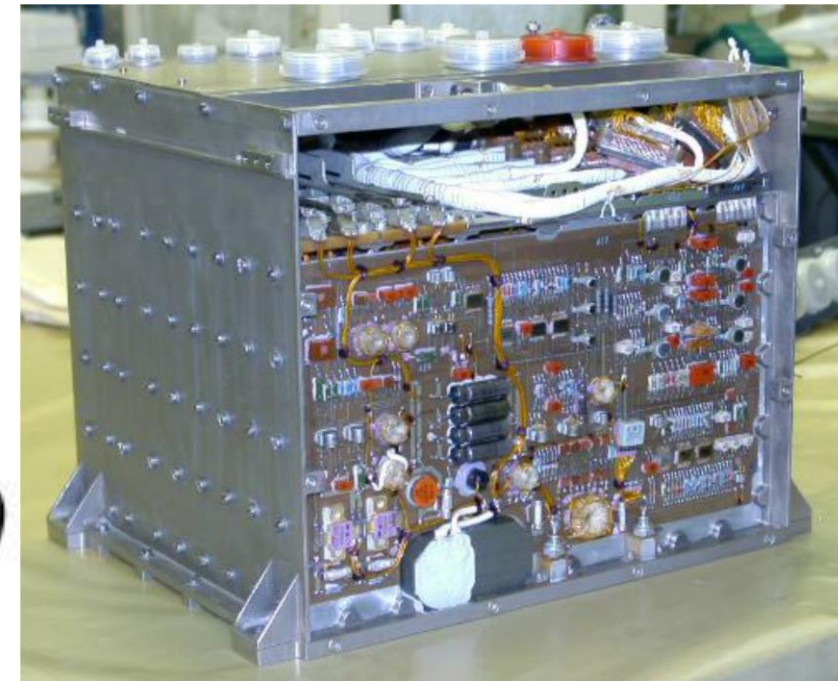
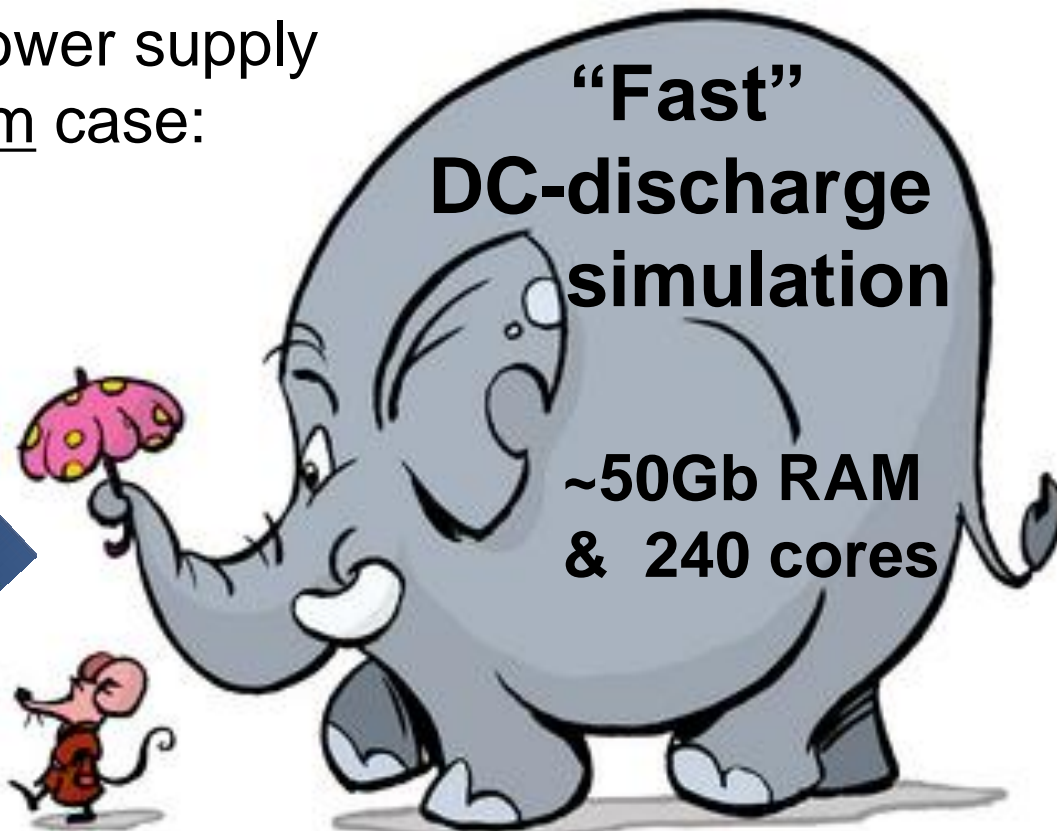
Device size ~ 500 mm,
Critical region ~ 1-5 mm
Debye length ~ 0.01-0.1 mm

Satellite secondary power supply
in 231x174x30 mm case:



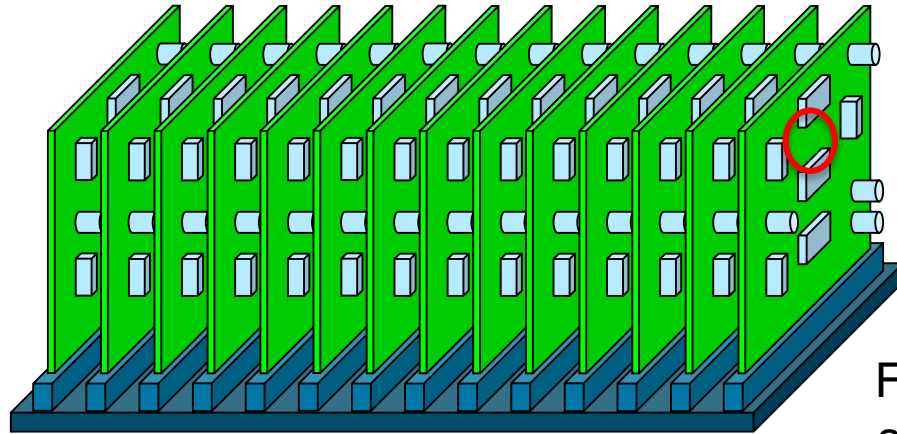
**“Fast”
DC-discharge
simulation**

**~50Gb RAM
& 240 cores**

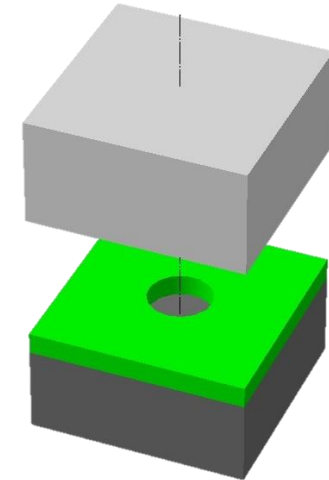


Our approach

1) Electric field-enhancement regions extraction

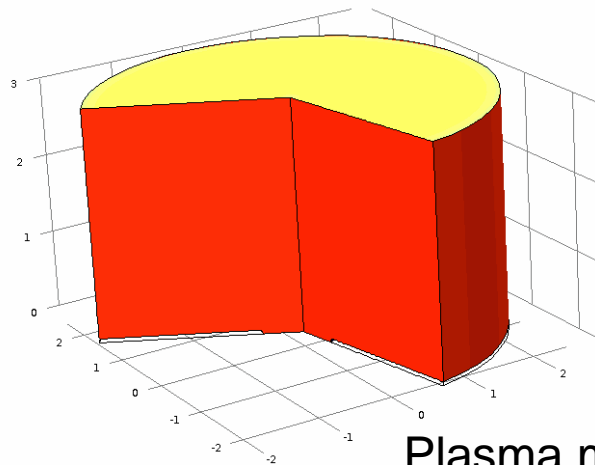


~~Debye length
scale~~

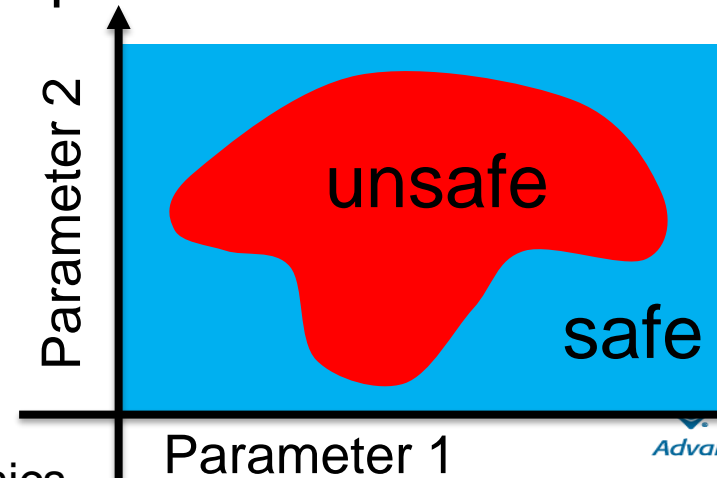


Full-scale SPICE + Electrostatics
simulation (AC/DC module of COMSOL Multiphysics)

2) DC-discharge simulation + Parametric sweep option



~~Device scales~~



Software interface

The screenshot displays the software interface for simulating electric potential on a PCB. The main window is titled "Untitled.mph - Untitled". The menu bar includes: Геометрия, Сетка, Напряженность, Напряженность (сечение), Разделитель, Электрический потенциал, Плазма 2D результат, Плазма 2D геометрия, Вывод.

The left sidebar contains the following sections:

- File:** Lists project files: NetC10_A2_2, NetC10_A1_2, NetC10_A1_1.
- Настройки сетки и запуск:** Includes a mesh quality dropdown (Extremely fine to Coarser) and a solver configuration window showing "Orthonormal null-space func", "Iter SolEst Dampin", "1 0.82 1.000000", and "Stationary Solver 1 in Elec".
- Buttons:** "Построение геометрии", "Построение сетки", "Запуск решателя", "Вывод результатов", "Сечение XZ", "Extra fine", "Построить сетку для сечения", "Посчитать сечение", "Вывод результатов".
- Настройки программы:** Includes parameters for dielectric permittivity (Диэлектрическая проницаемость), electric potential (Электрический потенциал), and PCB parameters (Параметры печатной платы).

The main 3D view area shows a volume plot of electric potential (V) on a PCB layout. The plot is color-coded from blue (-25V) to red (25V). A color scale legend on the right indicates the potential values. The PCB layout is shown in a 3D perspective view with a coordinate system (x, y, z) at the bottom left.

At the bottom right, there are control options: "Ручное управление" (Manual control), "Max: 27.00000000", "Min: -27.00000000", "Единицы измерения: V" (Units: V), and "About".

✓ COMSOL Application Builder

- Complete PCB (ASCII) file format import

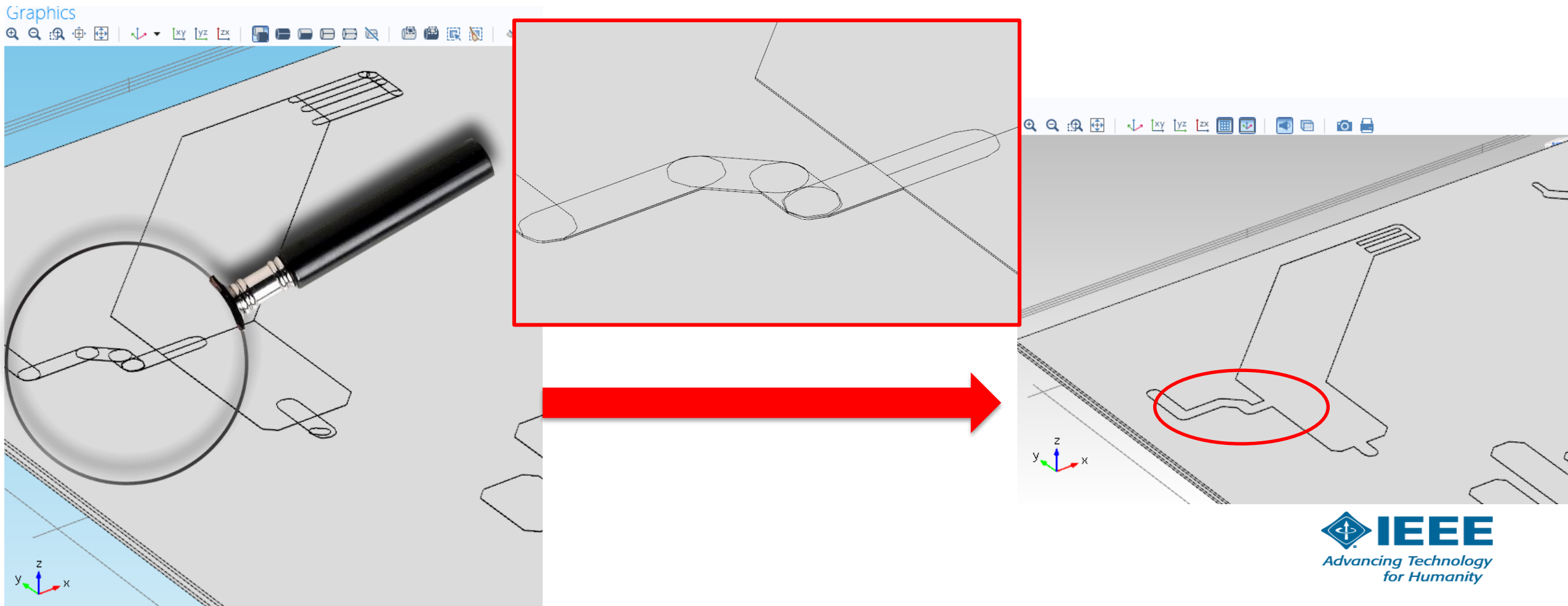
At the industrial partner “**JSC Reshetnev Information Satellite Systems**” request the PCB (ASCII) import was implemented in order to use Altium Designer files.

- Geometry improvements

We have designed native three-dimensional kernel to correct inaccuracies obtained during import.

Preprocessing module: Example

- Automatic removing of inaccuracies in geometrical details.



Live PCB import procedure

The screenshot displays the software interface for PCB simulation, divided into two main sections: the left sidebar and the main workspace.

Left Sidebar (Input and Settings):

- Входные компоненты (Input Components):** Shows file paths for "Плата 1" and "Плата 2", buttons for "Чтение платы 1" (highlighted), "Чтение платы 2", and "Импорт рамки".
- Цепи (Circuits):** Contains two empty panels labeled "Цепи платы 1:" and "Цепи платы 2:".
- Настройки сетки и запуск (Mesh and Run Settings):**
 - A dropdown menu for mesh quality with options: Extremely fine, Extra fine, Finer, Fine, Normal, Coarse (selected), Coarser.
 - Buttons for "Построение геометрии", "Построение сетки", "Запуск решателя", and "Вывод результатов".
 - Text: "Minimum element quality: 0.14".
 - Buttons for "Сечение XZ", "Построить сетку для сечения", "Посчитать сечение", and "Вывод результатов".
- Настройки программы (Program Settings):** Includes "Отладка" (Debug) and the number "14".

Main Workspace (Right Panel):

- Таблица вкладок (Tab Bar):** Includes "Геометрия", "Сетка", "Напряженность", "Напряженность (сечение)", "Разделитель", "Электрический потенциал", "Плазма 2D результат", and "Плазма 2D геометрия".
- Toolbar:** Contains icons for search, zoom, pan, and other navigation tools.
- Workspace:** A large empty area for visualization, with a 3D coordinate system (X, Y, Z) at the bottom left.

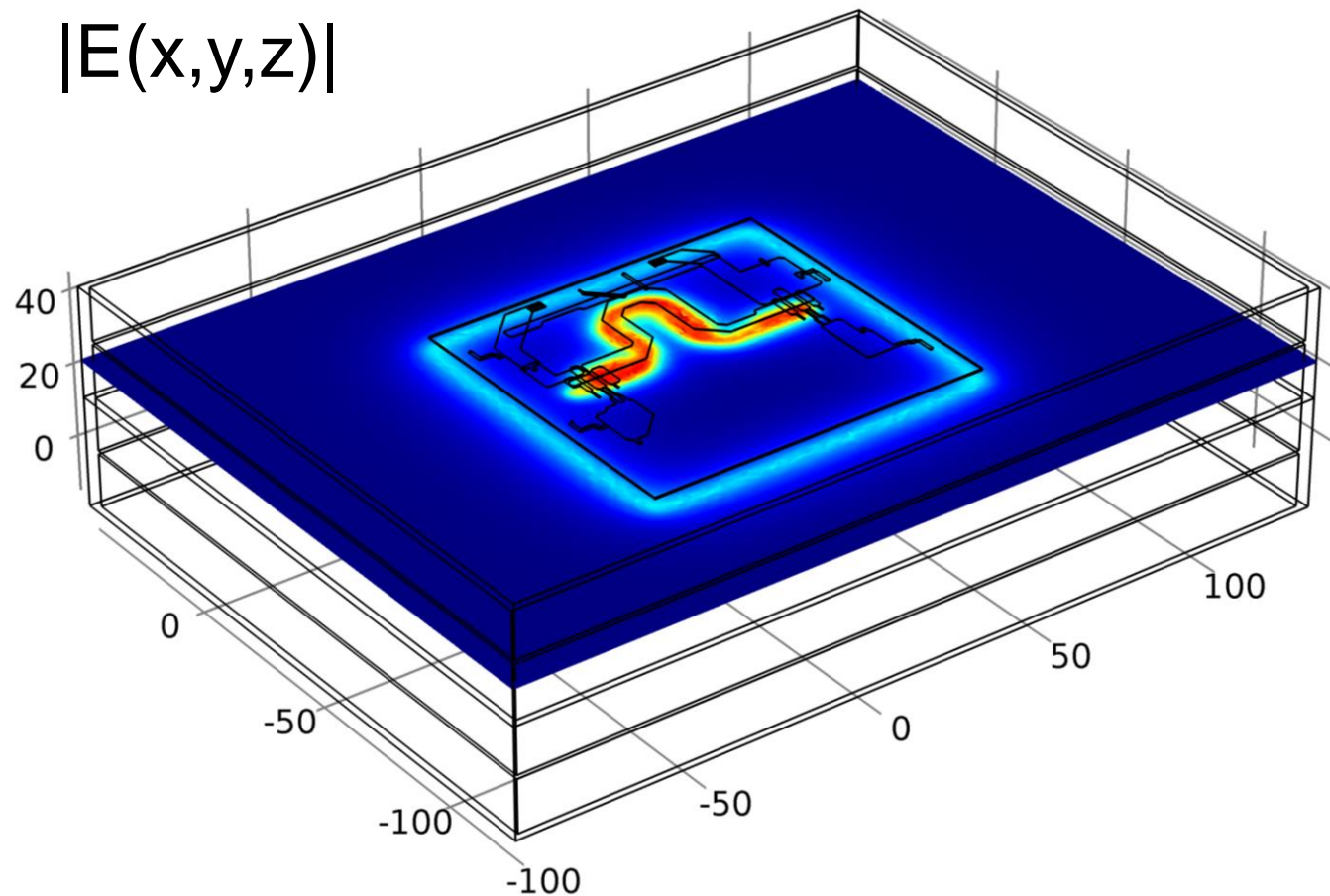
Processing module

- ✓ COMSOL Application Builder
- ✓ AC/DC Electrostatics + Plasma modules.
- Solve complete electrostatics problem
Find electrostatic potential and electric field absolute value distribution for defined geometry. Border conditions (potentials at conductors) are implied using SPICE simulation results.
- Critical regions location (by estimating of $|E|$ local maxima).
- Compile 2D models of critical regions from 3D using three coordinate sections
- DC-discharge simulation in 2D models with Parametric Sweep
(in order to obtain critical parameters diagrams)

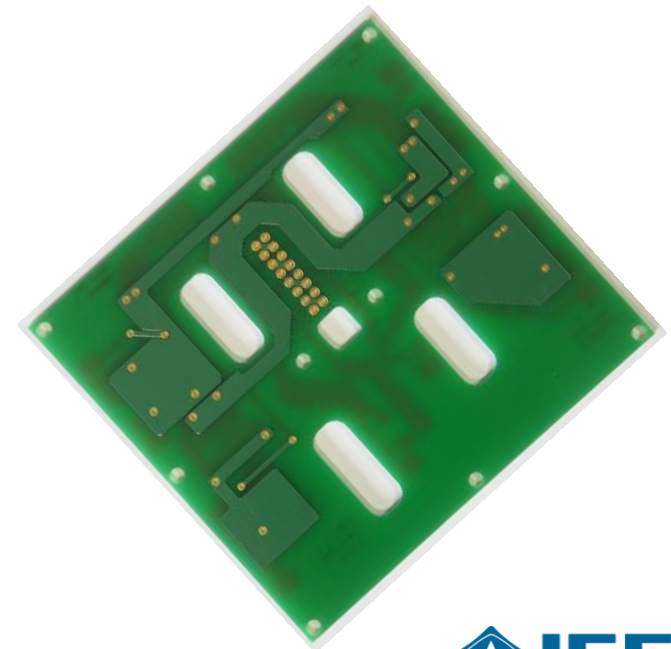
Electric field distribution

Full-scale SPICE + Electrostatics simulation (with AC/DC module of COMSOL Multiphysics)

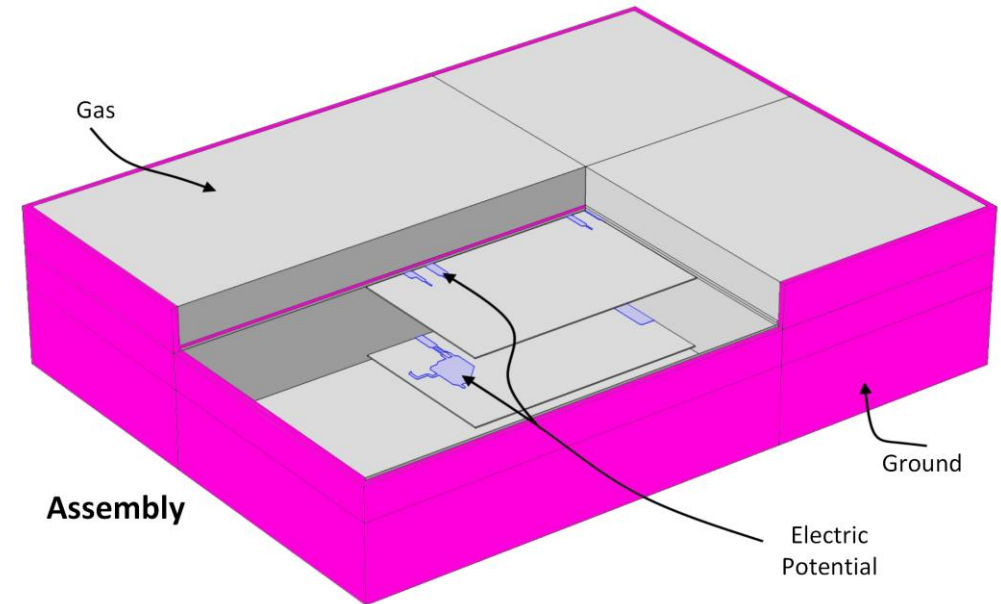
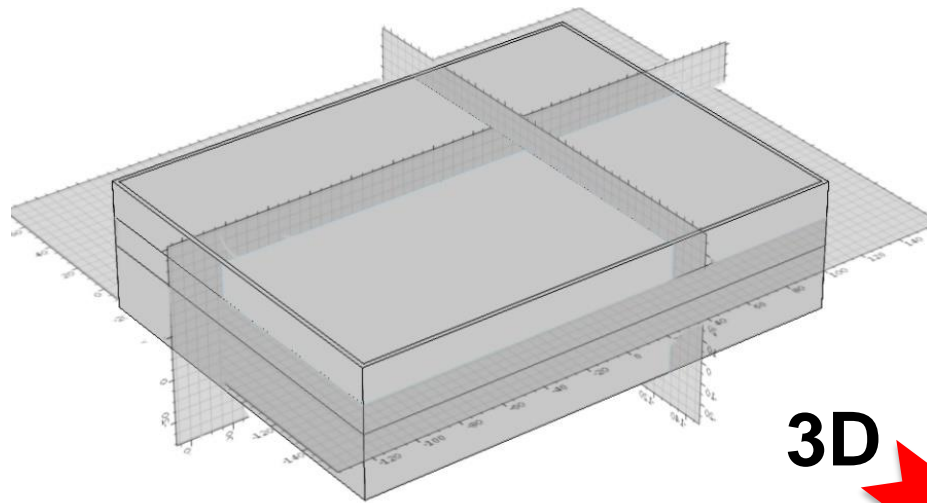
$|E(x,y,z)|$



Satellite secondary power supply PCB



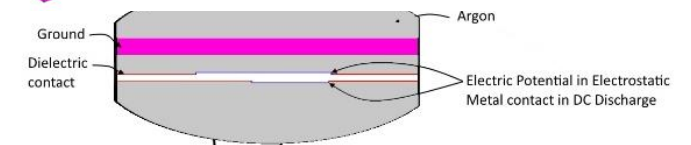
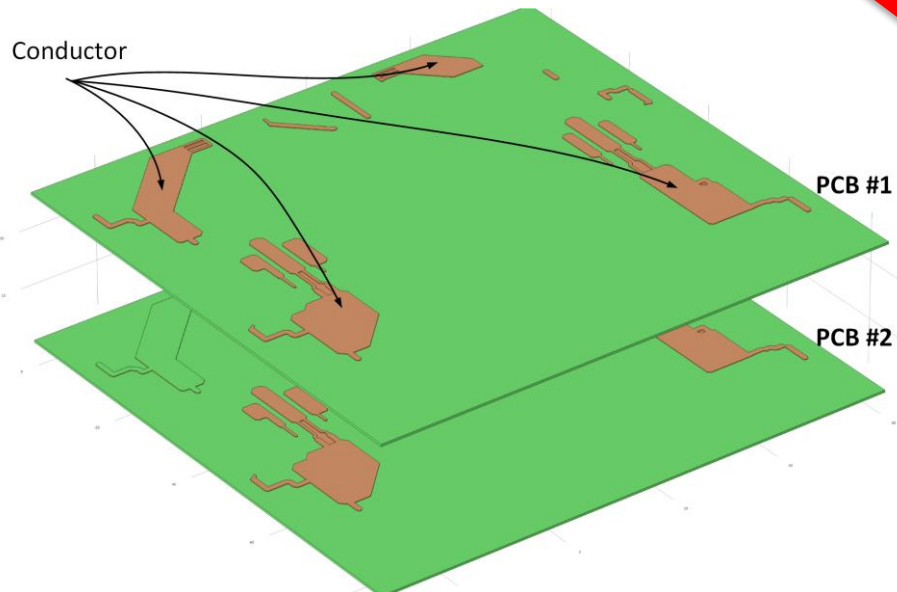
Location of critical regions



3D

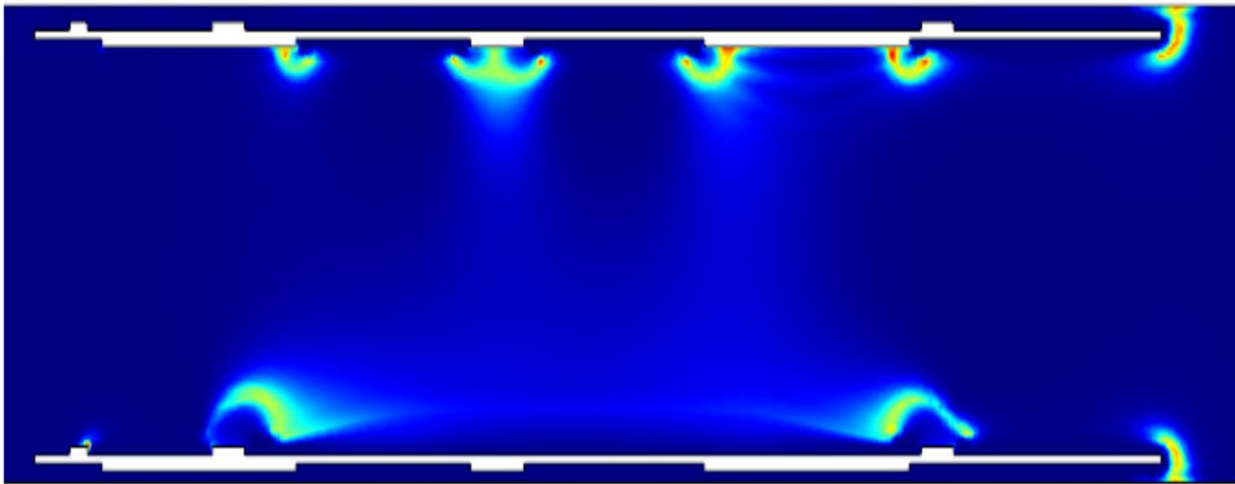
Assembly

2D

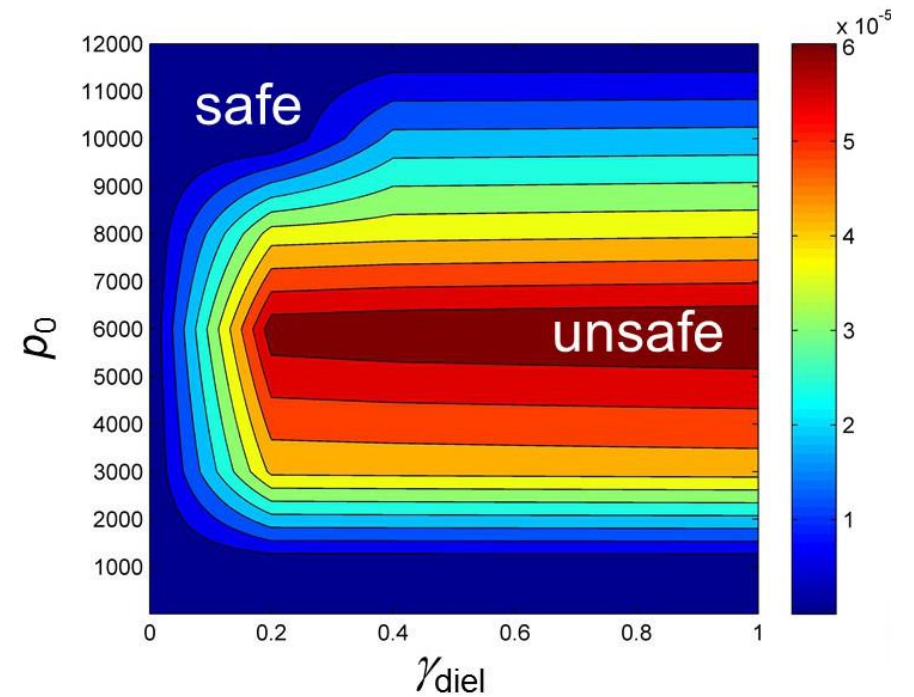


DC-discharge simulation

Computation of critical parameters diagrams using DC-discharge simulation (Plasma module of COMSOL Multiphysics) for each simplified model.



Electron density distribution



Critical parameters diagram

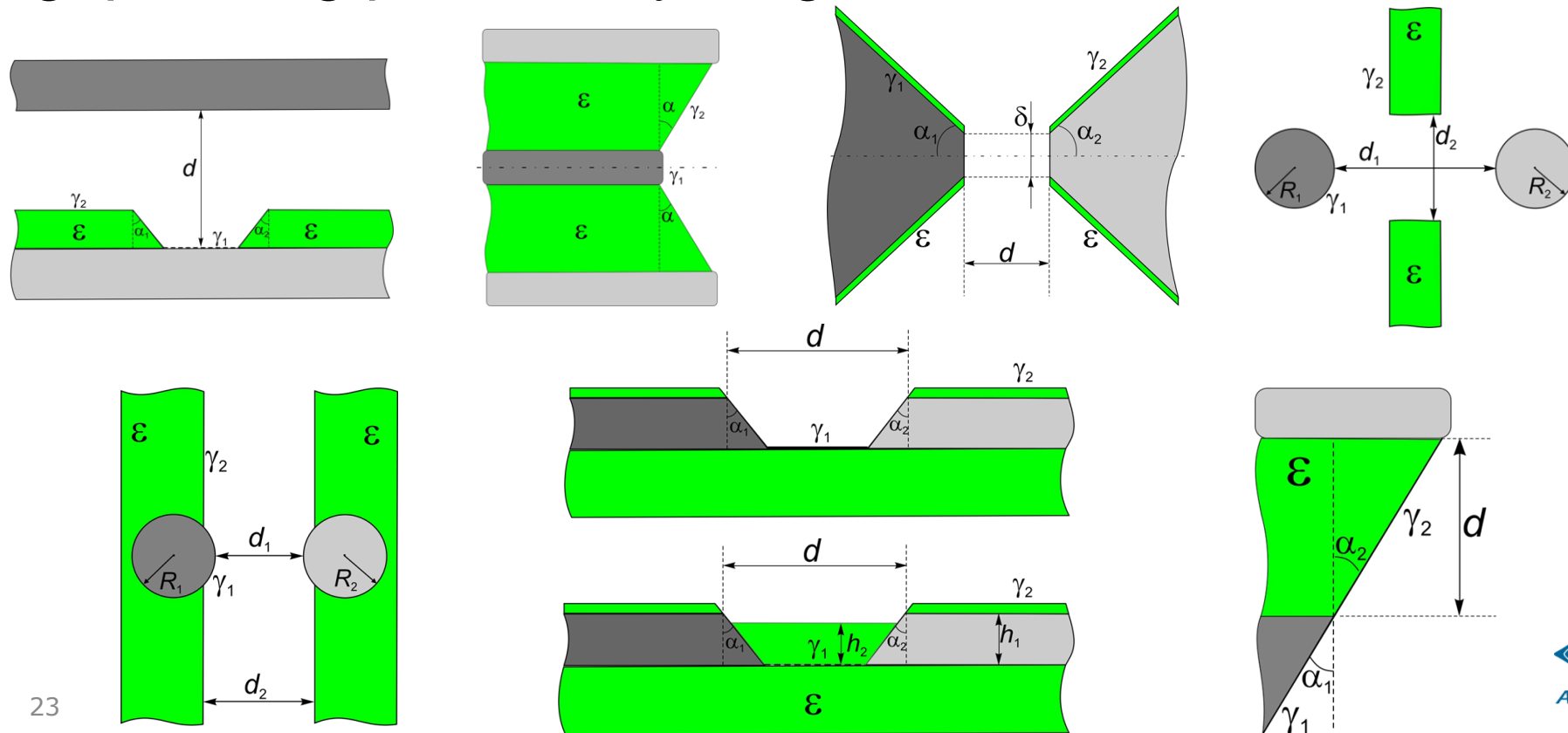
Summary

The previously proposed innovative computational approach has been successfully implemented in pilot software system completely built with COMSOL Multiphysics. COMSOL Application builder was used along with COMSOL AC/DC Electrostatics and Plasma modules in order to create a complete simulation cycle.

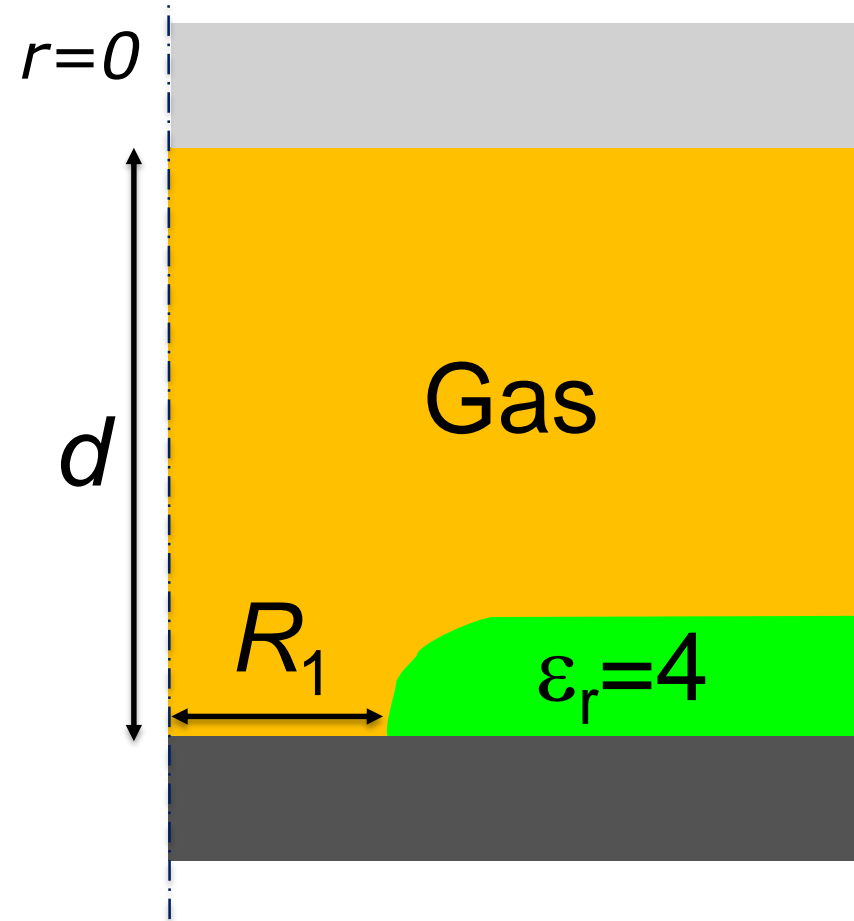
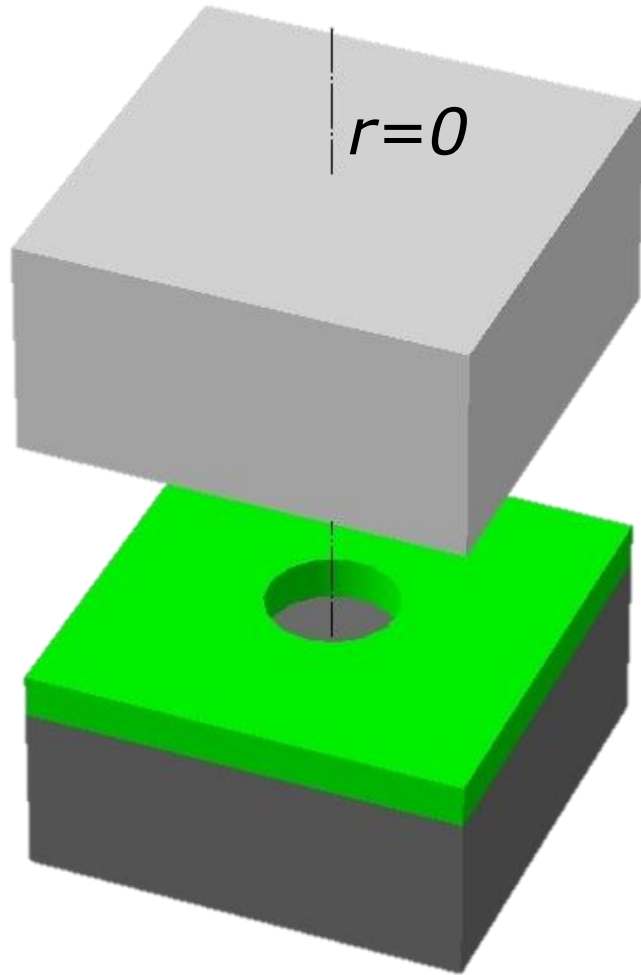
The developed software enables to combine possible arc positioning with the further investigation of certain regimes of the discharge ignition without full-scale DC-discharge simulation. The software allows upgrading the development technology of arc-resistant electronics intended for operation in the wide range of temperature, pressure and other environment or/and technical parameters.

Set of models (“zoo”)

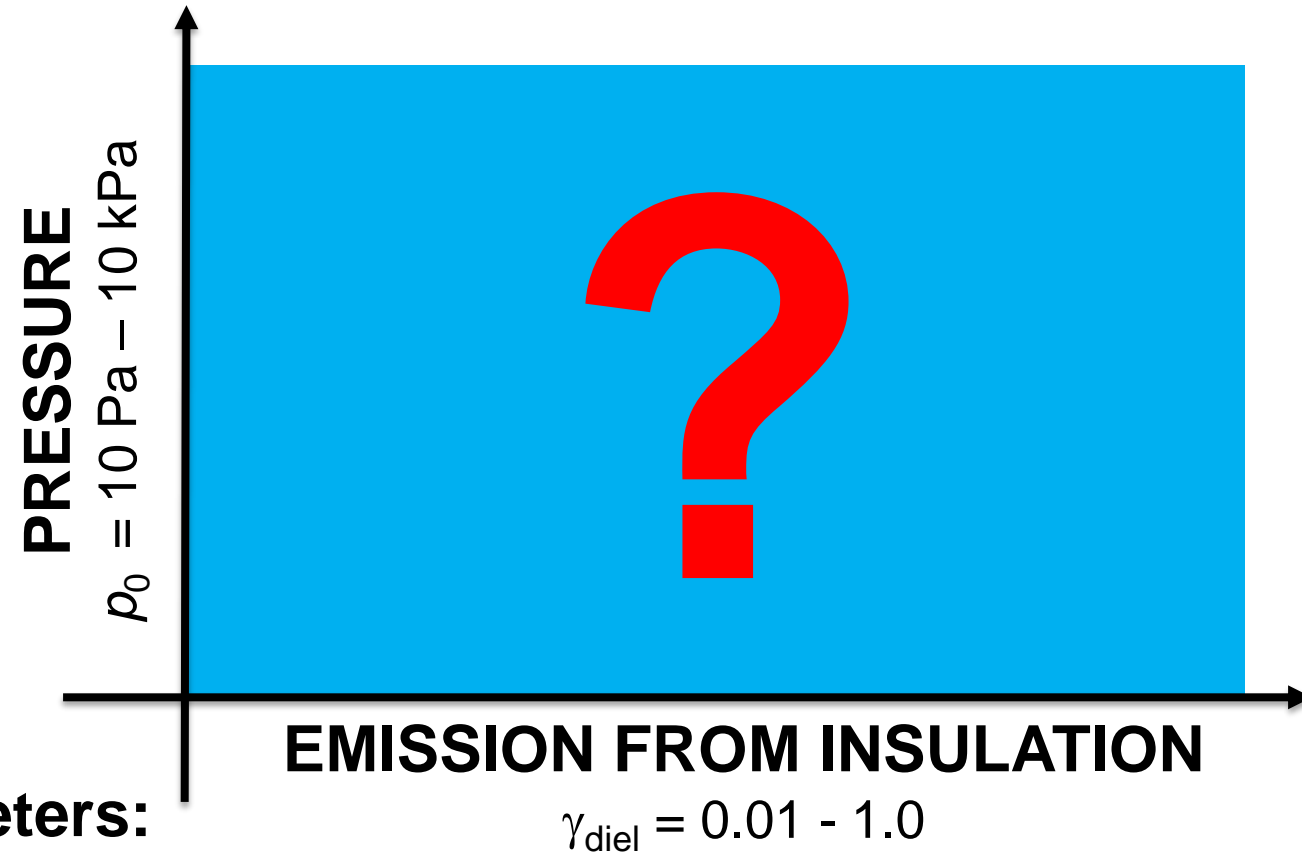
Drawing up of a set of simple two- and three-dimensional geometrical configurations of discharge gaps using preliminary diagnostics results



Circular defect in laquer insulating coating (2D-axisymmetric model)



Sample 2D critical parameters diagram ($\gamma_{\text{diel}} - p_0$ plot)



Other parameters:

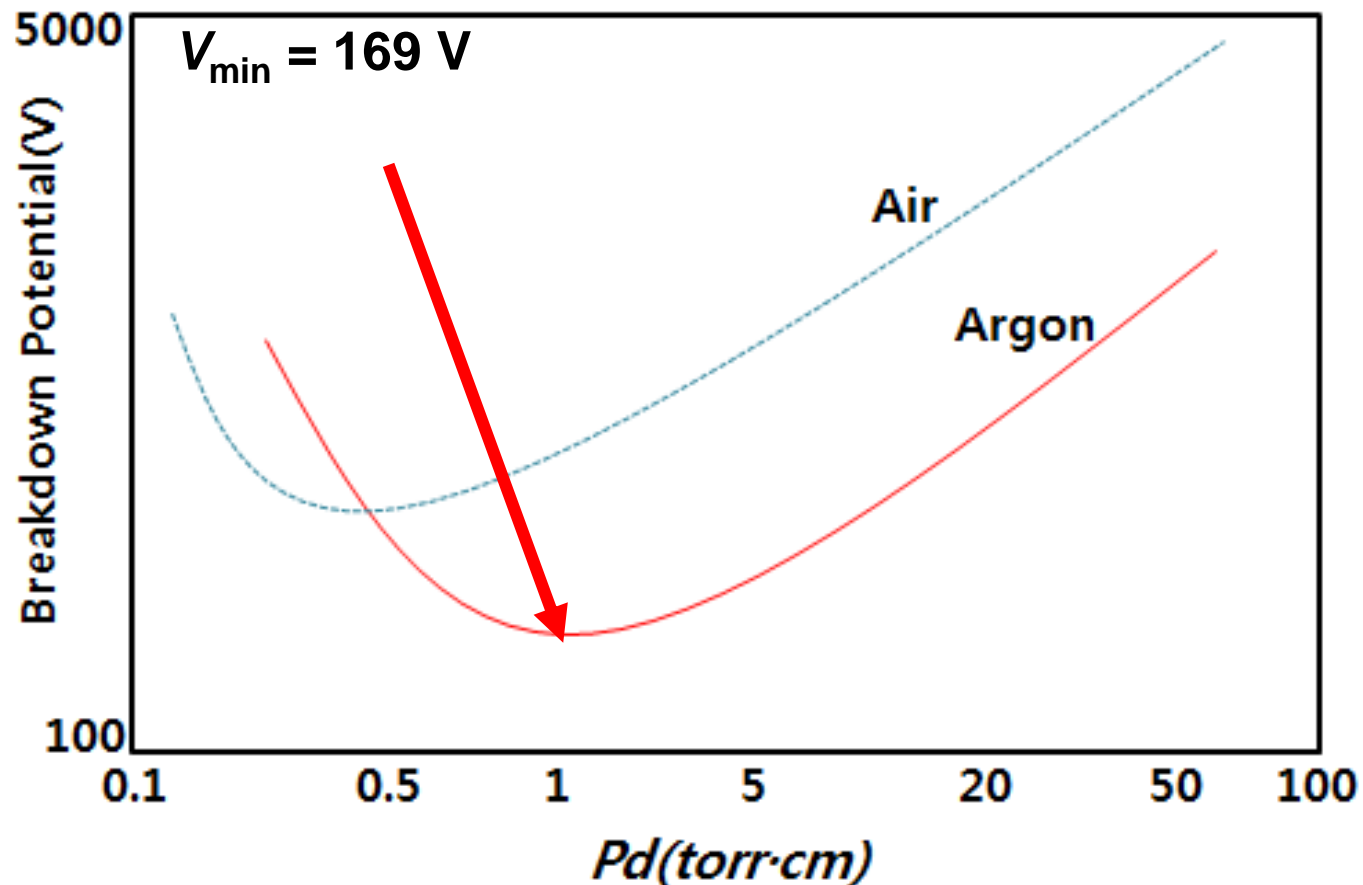
Interelectrode distance – 3 mm

Insulation thickness – 0.05 mm

Initial plasma density – 10^3 cm^{-3}

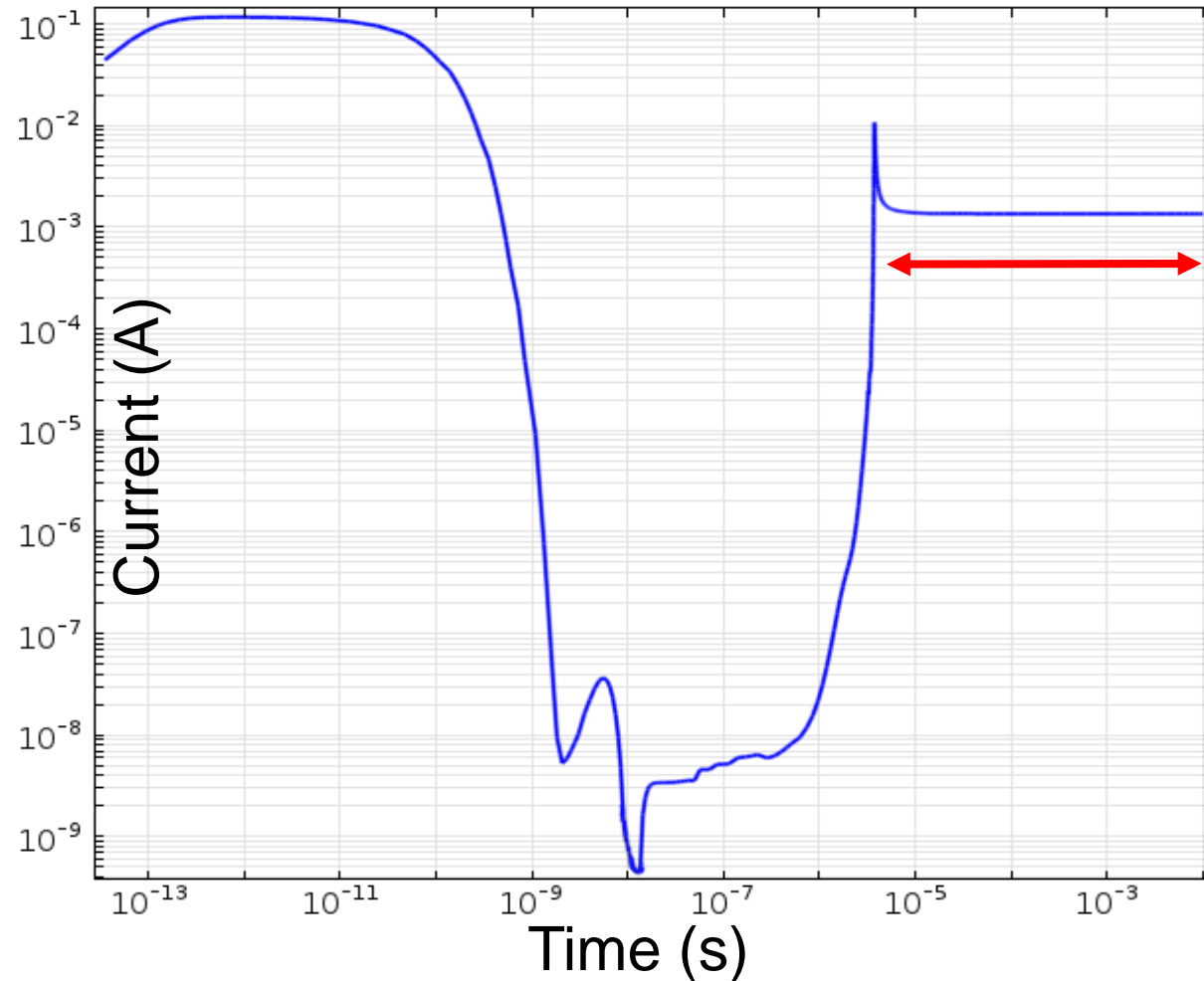
Applied voltage: two cases

- Reference case $V_0 = 200$ V (above Paschen's min.)
- Operating case $V_0 = 100$ V (below minimal breakdown voltage)

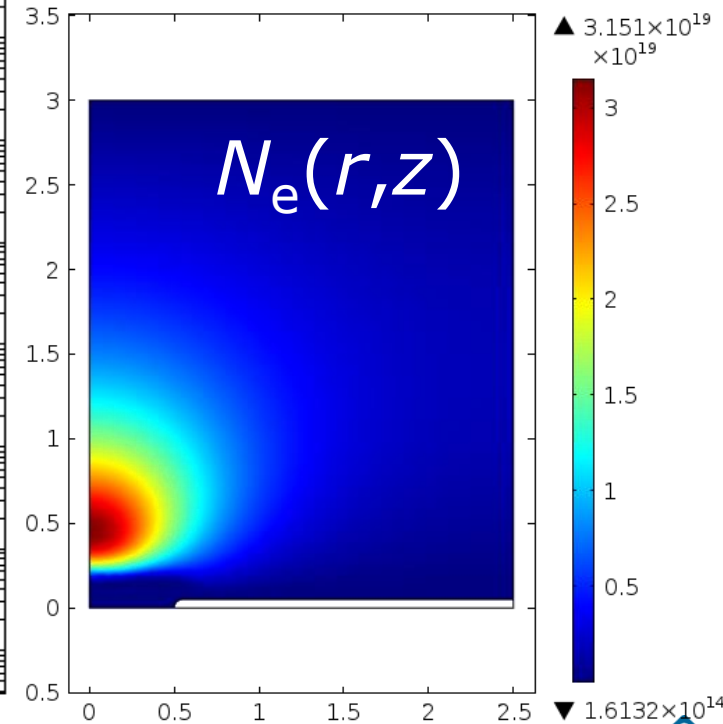


Reference case ($V_0 > V_{\min}$): Self-sustained discharge @ 1 ms

$V_0 = 200 \text{ V}$, $p_0 = 3 \text{ kPa}$

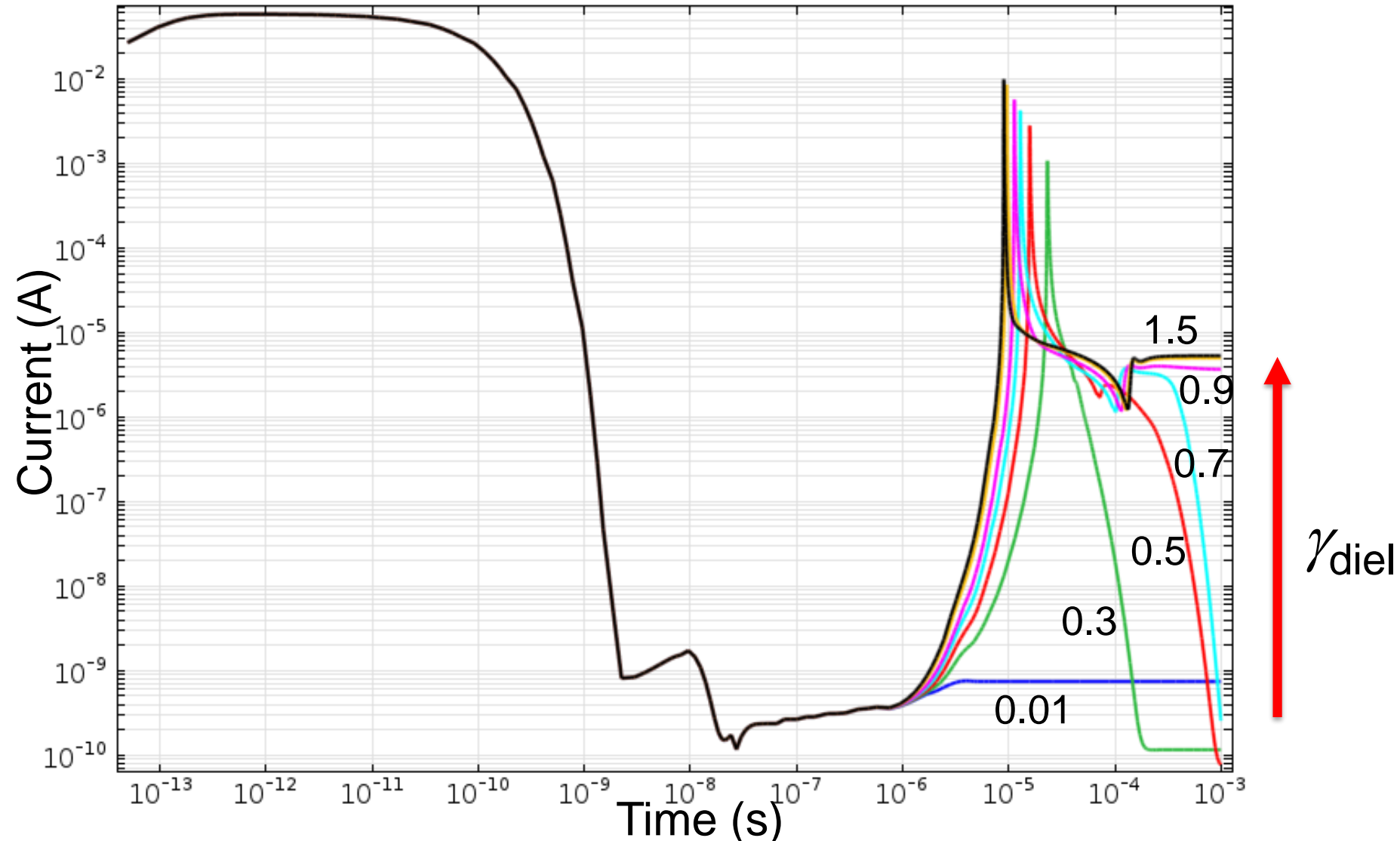


Electrons
density



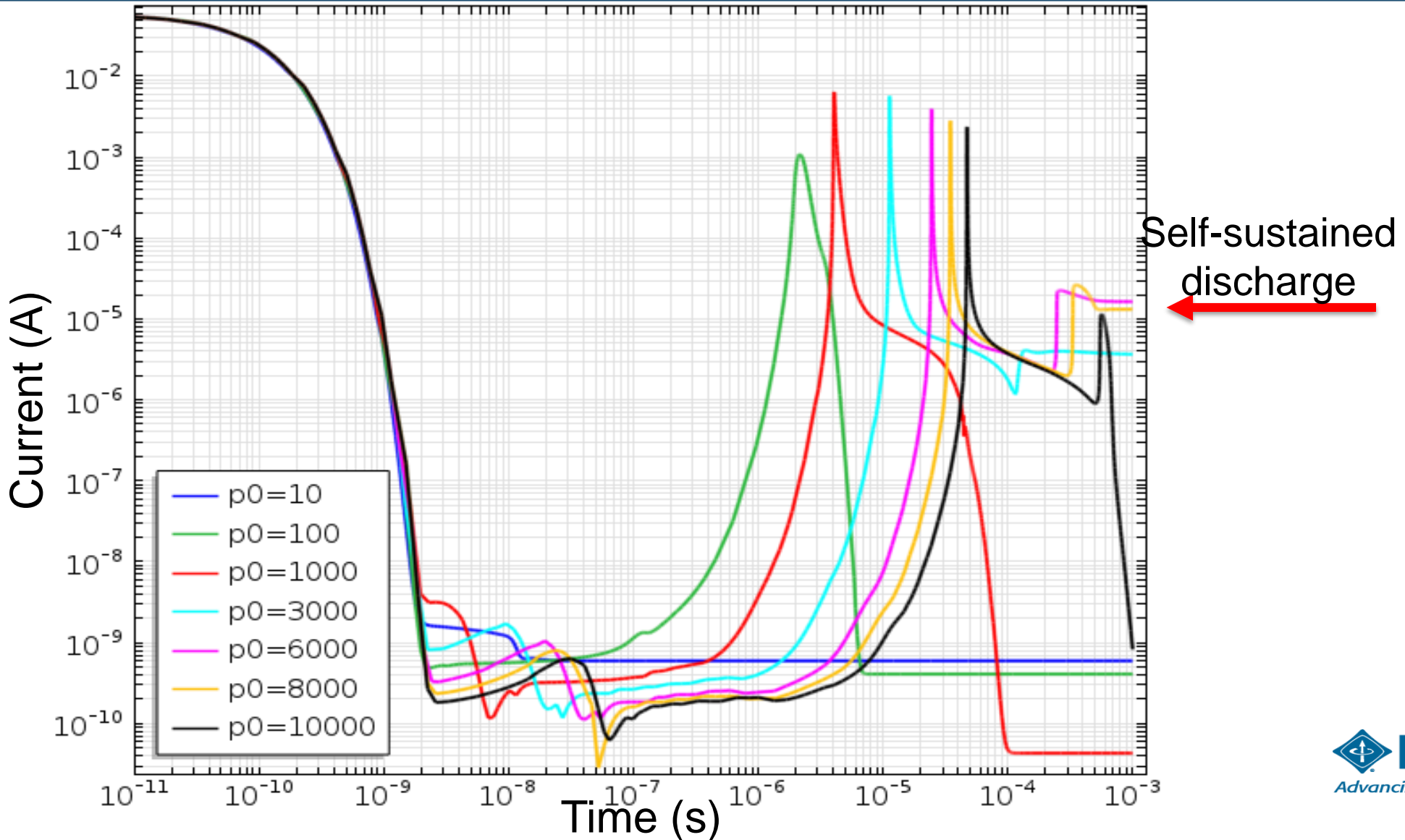
Operating mode

(γ_{diel} variation @ $p_0 = 3\text{kPa}$, $V_0 = 100\text{ V}$)



Operating mode

(pressure variation @ $\gamma_{\text{diel}} = 0.9$, $V_0 = 100$ V)



Critical parameters diagram (γ_{diel} , p_0)

